

EXPERIMENTAL RESEARCHES ON THE
REPULSION RESULTING FROM RADIATION

IN previous papers¹ I have described my earlier experiments with the radiometer, and I then showed that the movement of this instrument was due to the presence of residual gas. I have since examined the repulsion exerted by a standard flame shining on pith and mica disks, coated with various powders, chemical precipitates, &c., and suspended *in vacuo* in a torsion apparatus, and I propose in this and succeeding papers to give an account of these experiments, and of the concluding researches on the repulsion resulting from radiation.

The apparatus I used to get quantitative measurements of the repulsion produced by radiation on various kinds of disks, and coated with different substances, is similar to one I have already described, but in order that the experiments may be better understood, it is shown in Fig. 1. I append the following description:—

ab is a horizontal glass tube containing the beam,

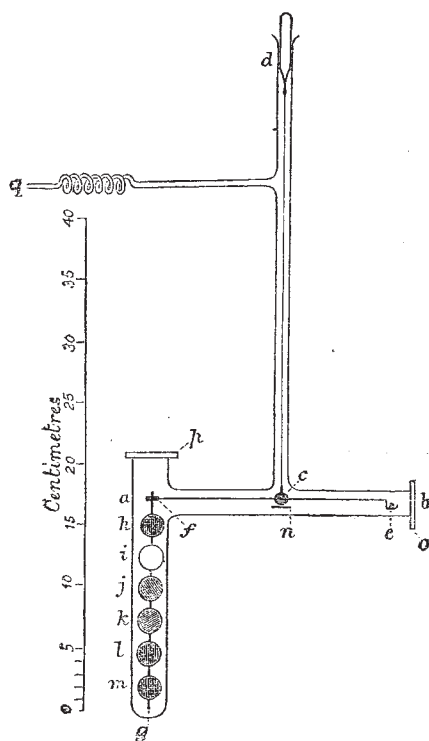


FIG. 1.

which, in this case, is made of straw, so as to secure lightness with absence of flexure under the comparatively heavy weights it sometimes has to bear; *cd* is a fine torsion fibre drawn from flint glass, to which the beam is suspended; it is cemented at *d* to a well-ground stopper, so as to admit of adjustment. When in position, cement, made by fusing together eight parts by weight of resin, and three parts of bees' wax, is run round the stopper. At *c*, the point of junction between the torsion-fibre and the straw beam, is a silvered glass mirror. At the end *e* of the beam, is a small pan to hold the weights counterpoising the disks, which are suspended to the other end. A flat stirrup of aluminium at *f* fits stiffly on the straw beam, and carries a flat glass fibre, *fg*, cemented to it so as to allow of no play, the straw beam, the aluminium hook, and the glass fibre being perfectly rigid. The experimental disks are fixed on the glass fibre by means

of a touch of cement at the back. The vertical tube is arranged to hold six disks, the top one, *h*, being always the same standard lamp-blackened pith; the others, *i, j, k, l*, and *m*, being changed each time. A small magnet, *n*, attached to the central mirror, and controlled by a bar-magnet outside, gives the power of bringing the beam to zero, should it happen to get out of adjustment, without having to melt the cement and alter the angle of the torsion fibre by turning the stopper *d*. Plate glass caps at *o* and *p*, cemented to the ground edges of the tubes, give access to the interior; *o* allows the counterpoises to be adjusted in the pan, and *p* allows the aluminium stirrup to be unhooked, and the whole of the disks to be lifted out together. The apparatus is connected to the mercury pump by the arm and spiral *q*. The weights and dimensions of the various parts of the apparatus are as follows:—

Weight of straw beam, mirror, magnetic needle, aluminium stirrup, and flat glass fibre, &c.	7.25 grains.
Average weight of six plain mica disks	2.40 "
Average weight of six plain pith disks	0.59 "
Length of straw beam, from centre of counterpoising pan to centre of disks	17.0 centimetres.
Length of arm from centre of suspension to centre of pan	7.6 "
Length of arm from centre of suspension to centre of disks	9.4 "
Glass torsion fibre—Length	23.0 "
" " Thickness	0.0013 inch.
Torsion with a glass weight hanging from it	15.75 seconds.

Fig. 2 shows the apparatus fitted up for experimentation. The disks are shown in position at *a*, a brick wall, *bc*, has holes pierced through it in two places, as shown, one hole, *d*, being opposite the centre mirror, and the other, *e*, opposite the disks. The aperture *d* is lined with card, lampblack inside, and the interstices between it and the bricks are well plugged with cotton wool. A water cell at *d* prevents radiant heat from the lamp getting to the apparatus. Through the hole *e* pass six card tubes, lampblack internally, 20 millims. diameter, and 23 centims. long. The tubes are firmly cemented to the wall, so that each shall be exactly central with its corresponding disk, and the outer end of each is closed with a cork. The space between the tubes and wall is well stuffed with cotton wool. The apparatus, being once fixed in position, is surrounded on all sides, as well as above and below, with cotton wool. Outside this is a row of glass bottles filled with water, and in front of all is a wooden screen. When protected in this manner, the inside of the apparatus is found to be free from disturbances caused by changes of temperature. When the disks have to be changed, air having been let in through the pump, access is easily obtained to the glass cap *p* (Fig. 1), and the cement being softened by heat, and the cap removed, the disks are lifted out together by seizing the aluminium stirrup with forceps. A fresh set of disks being introduced, the apparatus is again packed up and re-exhausted.

A lamp at *f* throws a narrow beam of light on the mirror of the apparatus, through the aperture *d*. The ray is reflected to the scale *g*, where its deflection from zero shows the angular movement of the torsion beam when one of the disks is repelled by radiation. The scale is 1½ metre from the reflecting mirror.

A standard candle (the kind employed in gas photometry, and defined by Act of Parliament as a "sperm candle of six to the pound, burning at the rate of 120 grs. per hour") is supported on a heavy stand, *h*, and can be raised or lowered by means of the sliding piece, *i*. Another sliding piece, *j*, carries a pointed wire projecting from it. The upright rod of the stand is graduated and numbered, so that when the sliding piece *j* is at mark 1,

¹ NATURE, vol. xv. pp. 224, 299.

the point of the wire is on the prolongation of the axis of tube and disk No. 1, and so on. Then, by sliding the candle up till the most luminous part of the flame is level with the point of the wire, it is known that the light will shine full on the disk under experiment. A half cylinder, *k*, covered with black velvet, protects the candle from draughts. The candle-stand *h* slides along a straight edge, *lm*, screwed to the bench, so graduated that by bringing a mark on the sliding stand to one of the divisions, it indicates the number of millimetres separating the surface of the experimental disk from the centre of the candle flame. The experimental powders are laid on one surface of mica or pith disks as a water paint, no cement being used to promote adhesion. Disks of mica or thin metal were punched, while other materials were cut or filed into the shape of disks 17.25 mm. in diameter.

The exhaustion, which had to be effected after each change of the experimental disks, was carefully brought to the same degree both by actual measurement on a McLeod gauge, and by getting the same repulsion on the standard black disk. In this way all the different results were fairly comparable one with the other. The presence of aqueous vapour was specially guarded

against by means of tubes containing phosphoric anhydride.

To show the effect of residual gas intertending to equalise the amount of repulsion on variously coloured surfaces, I devised an experiment with pith disks, one being lampblack and the other retaining its natural white surface, the standard candle being at the same distance in each case. When the exhaustion is good enough to cause a fair repulsion, the ratio between the amplitude of swing when the black is exposed, and that when the white is exposed, is as 100 : 55.5; at a little higher exhaustion the ratio is, Black : White :: 100 : 42.5; at a still better exhaustion the ratio is, Black : White :: 100 : 35. The results of the quantitative examination of the repulsion resulting from radiation when falling on about 100 different substances I have arranged in fourteen tables, for details of which I must refer to the Bakerian Lecture for 1878. The repulsion is measured, first when no screen is interposed, and secondly, when a cell of water is inserted in the path of the rays. In comparing the two results it must be remembered that the actual amount of repulsion on the standard lampblack disk, when the water screen is interposed, is only one-twelfth of the amount obtained when no screen is in the way, the distance of candle and

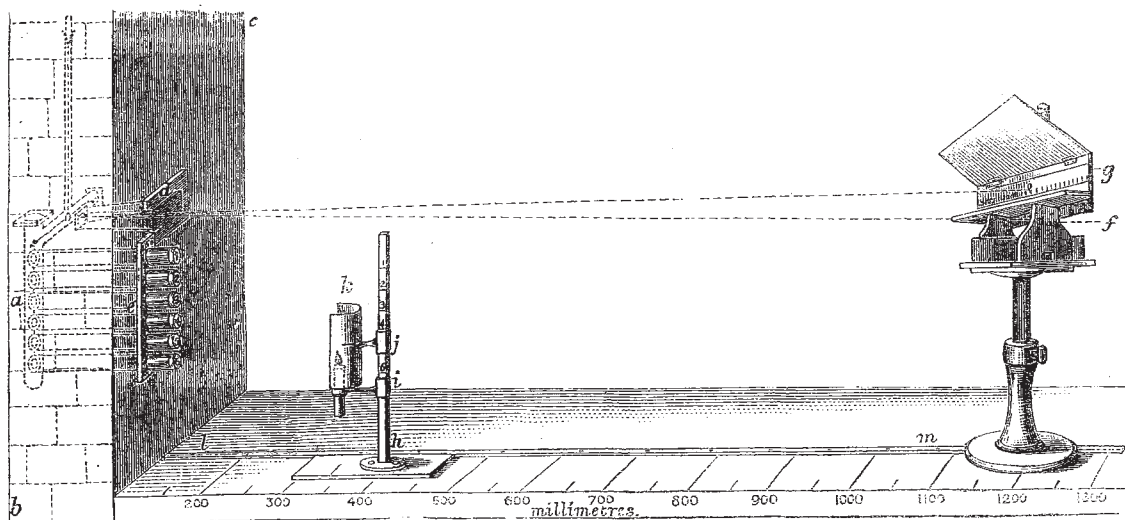


FIG. 2.

other things being equal. In order therefore to compare one with the other the result behind water must be divided by 12.

TABLE I.—Results of the Examination of Black Powders

Compared with lampblack = 100 these have an average value of 92.2, which becomes 99.1 by the interposition of water.

TABLE II.—White Powders

These have an average value of 33.5, which is reduced to 8.3 behind water. The powerful absorption for the invisible heat rays which white powders exercise is somewhat remarkable. Assuming that the ultra red rays from a candle are almost entirely cut off by a water screen, the comparatively strong action (33.5) produced by the naked flame must be mainly due to the absorption of the invisible heat-rays; and when these are cut off by water, the action is diminished nearly fifty times. With black powders the water only diminishes the action about eleven times.

TABLE III.—Red Powders

Amongst these precipitated selenium is noteworthy. To the naked flame its value is 35.8, but when a water

screen is interposed, the action becomes 69.5, in comparison with standard lampblack = 100. Omitting selenium, the mean action on red powders without a water screen is 32.2, and with a water screen, 24.9.

TABLE IV.—Brown Powders

Amongst these, peroxide of thallium is remarkable as being repelled under the influence of radiation to a greater extent than any other body hitherto examined, its value being 121.7, in comparison to lampblack = 100. Brown powders behave most like black, the averages of the columns *without* and *with* a water screen being 92.7 and 94.5.

TABLE V.—Yellow Powders

Among these, anhydrous tungstic acid resembles scarlet selenium in its anomalous action, the figures being, *without* water, 50.8, and *with* water, 72.2. The averages of the other yellow powders are 35.7, and behind water, 13.8.

TABLE VI.—Green Powders

These show some discrepancies, which will be referred to farther on.

TABLE VII.—*Blue Powders*

These show a much stronger proportionate action behind a water screen than with no screen, the averages being 55·8 and 65·2.

TABLE VIII.—*Dyes and Colouring Matters of Organic Origin*

Among these may be noticed saffranin, and a product of the decomposition of chlorophyll, which show an increased ratio of action when the heat-rays are cut off by water. Leaving out these, the mean actions of the other substances are, with no screen, 44·5, with a water-screen interposed, 28·1.

TABLE IX.—*Metals prepared in different Ways and coated with Lampblack, Mica, &c.*

Curious results are shown with iron and with gold, the former metal chiefly absorbing the invisible heat rays, whilst the latter metal is principally acted on by the luminous rays.

TABLES X. AND XI.—*Various Silver Salts*

The chloride, bromide, and iodide of silver in their different states were exposed to the standard candle after being submitted to the action of magnesium light, sunlight, and daylight. The results show how readily a change in the state of the surface is detected by an increased amount of repulsion under the influence of radiation.

TABLE XI.—*Selenium—Crystalline and Vitreous*

The former is in the state most sensitive to light action. With the crystalline disk results have been obtained which seem to show that the impact of light on its surface produces a superficial disturbance there and in the adjacent gaseous molecules, which takes some time to subside. This is connected with the change in electric conducting power of crystalline selenium—a change which, when the element is transferred from light to darkness, also takes some time to subside.

TABLE XII.—*Miscellaneous Substances—Pith, Mica, Charcoal, Glass*

The complicated nature of these actions was well shown in the results I obtained with three pith disks, the first being plain white, the second lampblack on the front, and the third lampblack on the back. The first was repelled with a power of 17·7, the second, which was the standard, with a power of 100, whilst the third was not moved at all. The repulsion exerted on the white surface must have been the same in each case, but the pressure *behind* the pith caused a radiation of heat from the back surface, which produced molecular pressure just sufficient to neutralise the pressure in front.

To show that physical condition has more effect in causing repulsion than chemical composition, I experimented with various kinds of charcoal. I found that the repulsion suffered by cocoa-nut shell charcoal is much less than that of white pith, being only 11·6 against 17·7. At the same time a radiometer made of cocoa-nut shell charcoal, lampblack on one side, was only moderately sensitive, instead of being superior to one made of pith lampblack on one side. The low figure shown by the charcoal was caused by its density enabling it to conduct heat from one surface to the other. Molecular pressure is therefore generated on both the back and front surfaces, and the figure I obtained is simply the difference between the two opposing actions.

I used other screens, besides water, to filter the radiation of the candle before it fell on the disk. I, however, preferred water. It is almost perfectly opaque to the invisible heat rays, and therefore its employment allows easy discrimination between actions due to heat and to heat and light combined; secondly, it is colourless, and

having no selective action on any visible ray of light, it can be used in conjunction with any coloured powder without complicating the results. Alum acts in a similar manner to water; coloured solutions act as water with a super-added action due to their colour. Very thick plates of glass have less action on the invisible heat rays than a thin layer of water. Sulphate of copper, in a solution so weak as to appear only slightly green, has a very strong action when artificial light is used, as it cuts off the lowest visible red rays as well as the ultra red.

I found that the substances I had experimented on might be divided into two classes.

1. *Negative*, those in which the repulsion behind water is *greater* in proportion to the standard than when no screen is present.

2. *Positive*, those in which the repulsion in proportion to the standard is *less* behind water than when no screen is present.

Amongst Class 1 may be mentioned copper tungstate, saffranin, scarlet selenium, and copper oxalate; these are more affected by light than by invisible heat. Amongst Class 2 I may mention pale green chromic oxide, persulphocyanogen, hydrated zinc oxide, barium sulphate, and calcium carbonate; these substances are more acted on by the ultra-red rays than by the luminous rays. To render these differences of action more comparable, I divided the averages obtained by the water

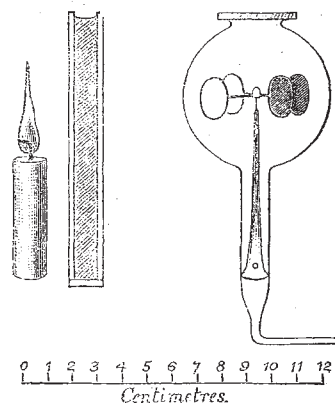


FIG. 3.

screen by twelve. Uniting the two classes together, the figures then became as follows:—

	No screen.	Water screen interposed (5 millims.)
Lampblack (standard disk)	100·0	8·3
Chromic oxide, pale green	71·5	1·7
Copper tungstate	51·2	6·4
Persulpho-cyanogen	43·9	1·0
Saffranin	41·0	4·3
Hydrated zinc oxide	40·5	1·2
Barium sulphate	37·4	0·3
Selenium, precipitated	35·8	5·8
Copper oxalate	30·1	3·3
Calcium carbonate	28·5	0·3

An examination of this table shows that the results can be proved by balancing one powder against another in a radiometer. A bulb was therefore blown on the end of a wide tube, as shown at Fig. 3. The top of the bulb was opened and turned over to form a lip; this was ground smooth and polished, so as to be readily closed by cementing on it a piece of plate glass. A glass stem supports a fine needle in the centre of the bulb, and on this rests a glass cap, to which is attached four radial arms of aluminium. To these arms disks of mica or pith can be fastened so as to form the movable fly of a radiometer. The disks can be changed by uncementing the glass top, and lifting the fly

out with tweezers. The lower part of the tube is drawn out for connection with the mercury pump. The powders used for experiment were carefully painted on the opposite sides of pith or mica disks, only water or alcohol being used.

Disks coated on alternate sides with chromic oxide and precipitated selenium move in one direction to the naked flame of a candle, and in the other direction when a water screen is interposed. With safranin and hydrated zinc oxide the instrument does not move at all when exposed to the naked flame, but revolves when a water screen is interposed. With thallic oxide and Magnus's green platinum salt, the instrument moves strongly when no screen is interposed, but is stopped with a water screen. These results are all in conformity with the figures.

A pith radiometer coated with precipitated selenium and chromic oxide was exposed to the radiation from a colourless gas flame from a Bunsen burner, coloured intensely green by thallium. To the eye, by this light, the chromic oxide looked nearly white, and the selenium black. The rotation due to the repulsion of the chromic oxide was, however, apparently as strong as when the non-luminous flame was used. This experiment proves that certain substances have an opposite absorptive action on rays of dark heat to what they have on light, and that an optically white body may be thermically black, and *vice versa*. In this case, for instance, chromic oxide was optically green, and thermically black, while scarlet selenium was thermically white and optically black. W. CROOKES

(To be continued)

METEOROLOGICAL ORGANISATIONS

IN the *Journal* of the Royal Statistical Bureau of Prussia for 1878, there is published a report on the meteorological organisations of the chief countries of Europe, Part I., by Dr. Gustav Hellmann, who is rapidly coming to the front as a first-class meteorologist. In addition to considerable mental capacity and much enthusiasm for the science, Dr. Hellmann has, at the instance, and with the assistance of the Prussian Minister of Public Instruction, especially qualified himself for the work by undertaking tours more or less prolonged, in the countries the meteorological systems of which he reports on. These in the Part before us are the various systems in France, Great Britain, Belgium, and Holland. With the aid of a renewed grant he sets out on a second tour, this time through northern Europe, especially Russia, for the purpose of presenting similar reports on the meteorology of these countries. This action on the part of the Prussian Government has been taken, in view of a contemplated reorganisation of its meteorological system, so that when the time comes, the system may be established, not at haphazard, but on a sure basis, founded on the fullest knowledge of the requirements of the science, and on the best means to be adopted for its healthy development.

The Weather Telegraph systems of France, Great Britain, Belgium, and Holland, are fully detailed, very special attention being given to the weather warnings of France, carried out for the benefit of agriculture and horticulture. This system of weather warnings, which is so peculiarly adapted to the wants of Germany, was, as our readers are aware, the last gift to meteorology of the great Leverrier, to whom, in its practical bearings, meteorology stands so deeply indebted.

As regards France, meteorology would appear to have a most hopeful future before it, as evidenced by the mental activity brought to bear on the science, the fertility of resource in devising new methods and subjects of observation, the breadth of view shown in making the study of weather and climate subserve great public interests, and withal by the pecuniary assistance liberally and heartily

given by Government and other bodies intrusted with the public funds, to the observatories, societies, and associations in various parts of France that are doing its meteorological work. Among the more special work France is doing may be noticed the application of the electric thermometer to the observation of the temperature of the air at great heights and of the soil at great depths; the establishment of several stations in Paris for the investigation of the chemistry and micrography of the atmosphere in their relations to the health of the city; and the establishment of high-level stations, which has been done largely through assistance given from the public purse.

We note with the liveliest satisfaction the great increase of meteorological stations over these four countries, the introduction of instruments for continuous observations in regions where they were much required, and a more adequate observation of the rainfall, particularly in the British Isles, where about 2,100 rain-gauges are at work, and in the river-basins of France, where the rainfall is noted at 1,111 stations.

Forcible attention is directed to the fact that in some cases the reduction of the observations and publication of the results are not carried out, or carried out very imperfectly, so that no little difficulty is experienced when conducting climatological inquiries, in obtaining the data from considerable portions of Western Europe. This defect ought to be rectified without delay.

Reference is made to international stations, or stations at which observations are made for purposes of international meteorology. But on looking at the diverse hours of observation adopted by the different European systems, it is evident that the attempt recently made to found an international meteorology must be regarded as a failure, since the prime and most elementary condition of uniformity as regards hours of observation has been neglected, the just views on this vital point propounded by Humboldt and the meteorologists of his time being at present, if appreciated, entirely set aside.

MYCOLOGY¹

IT is perhaps not generally known how very numerous are the specimens comprised under the branch Mycology. The mycological herbarium which is in the course of transmission to Kew consists of at least 10,000 species, of which 7,500, comprising the Hymenomycetes and Ascomycetes, have already been forwarded. But not only are many species very beautiful in form and colour, but the subject is one of great interest both in a physiological and economical point of view, apart from mere distinction of species and nomenclature, and, therefore, while especial journals are devoted to entomology, malacology, algology, and other branches of natural history, it is quite right that we should have one devoted to fungi. M. Roumeguère ought, however, to have mentioned that England already possesses one in *Grevillea* quite equal to the French journal, which has appeared with great regularity ever since 1872, and is monthly instead of trimestrial, of the existence of which he could scarcely be ignorant, as it is referred to more than once in the number before us.

The Journal before us commences with a paper on the much-vexed question of the real nature of lichens, in which the author is altogether opposed to Schwendener's theory of their parasitic growth on Algæ. There are two points which ought to be noticed: that the growth of *Gonidia* from *Hyphæ* was observed by Mr. Berkeley, as recorded in the "Introduction to Cryptogamic Botany,"² while the stem of the curious

¹ "Revue Mycologique: Recueil trimestriel consacré à l'étude des Champignons." Par M. C. Roumeguère. (Paris: J. B. Baillière et Fils.)

² "Int. Crypt. Bot.," p. 373, Fig. 78a.

³ "Int. Crypt. Bot.," p. 341, Fig. 76.